Quality of fresh-cut 'Kent' mango slices prepared from hot water or non-hot water-treated fruit

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ABSTRACT

This study addressed the effects of hot water (HW) quarantine treatment as mandated by the USDA-APHIS, for all mangoes imported to the United States, on the visual and compositional quality factors, aroma volatile production, respiration rate, and electrolyte leakage of fresh-cut 'Kent' mango slices during subsequent storage at 5 °C for 10 d. The experiment was conducted twice during two Florida mango seasons, with fruit from two different sources. Results from the two harvests were significantly different and therefore were analyzed separately. In general, the visual quality, electrolyte leakage, firmness, and aroma volatile production (based on the quantification of 16 aroma volatiles) did not differ between the fresh-cut slices prepared from HW- and non-HW-treated fruit. The fresh-cut slices from non-HW-treated fruit had higher soluble solids content than the HW-treated samples. There were also differences between the treatments for respiration rate, titratable acidity, and pH; but, the results were contradictory between the two harvests. Overall, the results suggest that the HW quarantine treatment applied to whole mangoes does not significantly affect the quality of fresh-cut 'Kent' mango slices stored at 5 °C.

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1. Introduction

The convenience and quality of fresh-cut fruit are factors in their increasing popularity in the food supply and so is the demand for various fresh-cut tropical and subtropical fruits. Mango (*Mangifera indica* L.), one of the most important tropical fruits in the world and currently ranked fifth in total world production among fruit crops (FAO, 2007), is considered to be a fruit with good potential for marketing as a fresh-cut product. However, little is known about mango physiology and shelf-life when processed into fresh-cut slices or chunks, and less information exists regarding fresh-cut mango flavor quality (Beaulieu and Lea, 2003) in order to commercialize a high quality product with acceptable shelf-life for marketing. For all mangoes entering the United States, a quarantine heat treatment consisting of exposure to 46 °C water for 65–110 min (depending on cultivar and fruit size) is mandated by the U.S. Department of Agriculture-Animal and Plant Health Inspection Service (USDA-APHIS, 2002; Schedule T102-a). It is known that heat treatments may have positive effects on fruit quality such as extending storability and marketing by inhibiting ripening processes or inducing resistance to chilling injury (CI), and

altering the volatile profile of whole fruit (Lurie, 1998; Paull and Chen, 2000; Fallik, 2004). However, the USDA-APHIS heat treatment can also cause heat injury to develop in mangoes, at both external and internal levels. Heat treatments were reported to accelerate ripening in mango varieties such as 'Keitt' (Jacobi and Giles, 1997) and 'Tommy Atkins' (Talcott et al., 2005). Accelerated water loss and failure to achieve the desired peel color are also common in heat-injured fruit (Joyce et al., 1993). Moreover, internal injury includes poor color development, abnormal softening, lack of starch breakdown, and development of internal cavities. In addition, heat-injured fruit can fail to color and can either soften quickly or show abnormal softening in which some areas of the flesh remain hard while others soften (Lurie, 1998; Jacobi et al., 2001). Therefore, the use of heat-treated mangoes for fresh-cut processing may compromise the composition and or the sensory quality of the product. This study addresses the effects of the USDA-APHIS hot water (HW) quarantine treatment on the visual, and compositional quality factors, aroma volatile production, respiration rate, and electrolyte leakage of fresh-cut 'Kent' mango slices during subsequent storage at 5 °C for 10 d. To the best of our knowledge, this is the first report to address the direct effect of quarantine heat treatments on fresh-cut mango quality and shelf-life. A previous report by Plotto et al. (2006) involved treatment of mango with ethanol vapor prior to fresh-cut processing where there was a 4 or 7 d period at 20 °C between heat treatment and ethanol treatment/processing.

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2. Materials and methods

2.1. Plant material

This study was conducted twice during two Florida harvest seasons. Mangoes (cv. Kent) were obtained from a commercial operation in Homestead, Florida [first harvest (H1), July 2006] and from the University of Florida Tropical Research and Education Center in Homestead, Florida [second harvest (H2), July 2007]. Fruit were removed from the field with minimal delay after harvest and transported to the postharvest laboratory in Gainesville, Florida, within approximately 6 h. Mangoes where selected based on uniformity of size, color, and freedom from defects. Half of the fruit received the quarantine hot water (+HW) treatment following the USDA-APHIS treatment schedule T102-a (USDA-APHIS, 2002). Mangoes were immersed in water at 46 °C for 90 or 75 min for fruit with weights greater than 500 g or less than 500 g, respectively. The other half of the mangoes (-HW) were used as a control and where immersed in water at room temperature (24 °C) for 2 min to remove sap on the skin. Following the HW treatment, all treated fruit were left for about 90 min at room temperature to cool down and dry before being transferred to a 20 °C temperature controlled room for a 24-h ethylene treatment (100 $\mu L L^{-1}$). Following ethylene treatment, the fruit where allowed to ripen at 20 °C until the desired ripeness stage was attained as determined by flesh firmness that yielded to gentle hand pressure (3–4 d after ethylene treatment), which resulted in slices with average initial firmness of 33.0 ± 4.5 N (H1) or 29.2 ± 3.8 N (H2). The ripe mangoes were held overnight in a sanitized and refrigerated room at 5 °C. Half of the fruit from each treatment (+HW or −HW) were processed into fresh-cut slices while the other half were left whole (control). Before being peeled, mangoes received a 3-min, 100 $\mu L L^{-1}$ chlorinated 5 °C water bath, adjusted to pH 7 with 0.67 $mol L^{-1}$ citric acid solution. After peeling, mangoes were submerged in another 100 $\mu L L^{-1}$ chlorinated 5 °C water bath before being drained and cut into slices. Each mango for fresh-cut was halved and cut into eight slices. All mango slices from mangoes from the same treatment (+HW or −HW) were pooled together and randomized before being distributed into containers made of polyethylene terephthalate (PETE). The leak free snap-on cover was pierced with a 1.5-cm diameter hole that was filled with a cotton ball to both assure good air circulation and avoid microbial contamination. Whole fruit controls and a total of 8 mixed slices per container were stored at 5 °C for 10 d. Four whole fruit and four containers of fresh-cut slices per treatment were used for analyses at each sampling time. Prior to analysis, the whole fruit were processed into fresh-cut slices as described above.

2.2. Visual analysis

The visual quality of each sample of fresh-cut mango slices was assessed on days 0, 2, 5, 7 and 10 at 5 °C using a 9-point visual rating scales for overall color, edge tissue damage, spoilage, aroma, and desiccation with higher numbers corresponding to better quality as previously reported by Beaulieu and Lea (2003). All visual evaluations were performed by the same trained person.

2.3. Respiration rate measurements

Four containers of fresh-cut and four whole fruit for 120 each treatment were all individually sealed for 1–2 h in 2-L plastic containers prior to sampling for respiration determinations. A 0.5-mL headspace sample was withdrawn by syringe through a rubber septum, initially and after sealing, and carbon dioxide concentration was determined using a Gow-Mac (Series 580, Bridge Water, NJ) gas chromatograph (GC) equipped with a thermal conductivity detector (TCD) and a 1219 mm × 3.18 mm, 80/100 mesh Porapak Q column. The detector and injector were operated under ambient conditions (26–27 °C), the oven temperature was at 40 °C, and the carrier gas (helium) flow rate was 8.3 $\mu L s^{-1}$ at 275.79 kPa. Respiration rate measurements were conducted using the same samples on days 0, 2, 4 and 8 at 5 °C for H1 and on days 0, 3, 4, 6 and 8 at 5 °C for H2.

2.4. Conductivity analysis—electrolyte leakage

Twelve mesocarp tissue plugs (5 mm diameter × 10 mm) per 8-slice sample were excised from fresh-cut slices using a brass cork borer. The mesocarp plugs were cleaned of damaged cells by rinsing gently with deionized water before being incubated in 30 mL of 0.7 $mol L^{-1}$ isotonic mannitol in water at room temperature for 3 h. The electrical conductivity of the solutions was measured using an YSI Conductivity Instrument (YSI Inc., Yellow Springs, OH). Total electrolytes were determined after freezing at −20 °C, thawing, and re-warming to room temperature. Three measurements per sample were taken. Electrolyte leakage was expressed as a percent of the conductivity of total tissue electrolytes.

2.5. Firmness evaluation

In H2, firmness was measured using an Instron Universal Testing Instrument (Model 4411, Canton, MA) fitted with a flat plate probe (5-cm diameter) and equipped with a 50-kg load cell. The non-destructive measurements were made on four fresh-cut slices per sample, positioning the probe over the largest flat side of each slice, after establishing zero force contact between the probe and the equatorial region of the fruit, the probe was driven with a crosshead speed of 0.833 $mm s^{-1}$. The force was recorded at 2.5 mm deformation, and the results were reported in newtons.

2.6. Flesh color measurements

In H2, superficial flesh color measurements (L^*, a^* and b^*) were taken with a reflectance colorimeter (Minolta CR 200b, Minolta Corp., Ramsey, NJ) on the cut surface of mango slices. There were 10 measurements made per treatment from 10 slices from four containers. Numerical values of a^* and b^* were converted into hue angle ($H^\circ = \tan^{-1} b^*/a^*$) (Francis, 1980).

2.7. Compositional analysis

Samples destined for compositional measurements were homogenized, and kept frozen at −20 °C in air-tight plastic bags until analysis.

2.7.1. pH, titratable acidity and soluble solids content

Each individual sample replicate was thawed, and a 50-g aliquot of the tissue slurry was centrifuged at 17,600 × g for 25 min. The clear juice was decanted from the centrifuge tubes and the pH and titratable acidity were determined using an automatic titrimeter (Metrohm Ion Analysis Ltd., model 719 S Titrino, Switzerland). Aliquots (6.00 g) of mango juice were diluted with 50 mL distilled water and the titratable acidity determined by titration with 0.1 $mol L^{-1}$ sodium hydroxide (NaOH) to an end point of pH 8.2. Titratable acidity was expressed as percent citric acid. The soluble solids content (SSC) of the resulting clear juice samples was determined with an Abbe refractometer (Cambridge Instruments, Inc., Buffalo, NY) and expressed as percent juice fresh weight.

2.7.2. Total ascorbic acid

For each sample, 2.5 g of homogenized mango tissue were mixed with 50 mL of a mixture of 6% metaphosphoric acid and 0.67 $mol L^{-1}$

acetic acid. Samples were kept frozen in glass containers at $-20\,°C$ until analysis. After thawing, the fruit–acid mixture was centrifuged for 20 min at $17,600 \times g$. The analysis was performed by the dinitrophenylhydrazine method of Terada et al. (1978). The concentration of total ascorbic acid was calculated from absorbance measured at 540 nm using a standard curve prepared from a serial dilution of an ascorbic acid standard solution (Sigma–Aldrich Co., St. Louis, MO). Concentration of ascorbic acid was expressed in terms of fresh weight.

2.7.3. Volatiles

Volatile samples were prepared by combining 1.5 g of mango homogenate with 1.5 g of distilled water in a 10-mL gas chromatography vial, crimp-capped and flash frozen in liquid nitrogen. The samples were stored at $-20\,°C$ before analysis. The headspace analysis was conducted using an Agilent 6890N GC equipped with a flame ionization detector (FID) and a $0.53\,mm \times 30\,m$, $1.0\,\mu m$ film thickness, polar Stabiliwax column. Volatiles were quantified using calibration curves obtained from deodorized mango homogenate, where volatiles are first removed by rotary evaporation (Malundo et al., 1997; Plotto et al., 2006), then spiked with five levels of authentic standards (Sigma–Aldrich). Sixteen aroma volatiles were measured and quantified: acetaldehyde, hexanal, acetone, methanol, ethanol, α-pinene, β-pinene, limonene, ρ-cymene, α-copaene, 3-carene, myrcene, terpinolene, caryophyllene, ethyl acetate and ethyl butyrate.

2.8. Statistical analysis

A completely randomized design was used for this study with evaluation or analysis of composite samples of eight slices from four replicate containers per treatment and sampling time, except that 10 color measurements were made on 10 slices taken from 4 containers per treatment and sampling time. The visual evaluation scores were transformed by the arcsine square root method using radians for statistical analysis. Data were analyzed using the General Linear Model procedure of SAS (SAS Institute, version 9.1, Cary, NC), to identify significant main effects due to storage time, fresh-cut versus whole, and heat treatments. Significant differences between treatments were detected using the least significant differences (LSD) test at the 5% level. The seasons of harvest (H1 and H2) were found to have significantly different effects for all treatments evaluated, and were therefore analyzed separately.

3. Results and discussion

3.1. Subjective visual quality

Storage time had a significant effect on the visual quality of fresh-cut mango slices stored at $5\,°C$ (Table 1). During storage, the visual quality of fresh-cut 'Kent' mango slices from both harvests decreased consistently (Fig. 1). In H1, the shelf-life of fresh-cut mango slices was limited by edge tissue damage, characterized by edges that were slightly soggy or water-soaked with darker color, veins markedly browning, and a gooey appearance, while the limiting factor of marketability in H2 was desiccation, characterized by a progressive drying of the slice edges with little to no surface gleam, and slightly dehydrated surfaces. The shelf-life of fresh-cut slices at $5\,°C$ was, for both harvests, limited to 5 d. Similarly, Beaulieu and Lea (2003) reported that shelf-life of fresh-cut mango cubes from soft-ripe mangoes was limited to 7 d when stored at $4\,°C$ and the most critical factor reducing quality was edge or tissue damage, resulting in mushy tissue and poor texture, followed by aroma loss and general discoloration. Different shelf-lives for fresh-cut mango

have been reported in the literature: Rattanapanone et al. (2001) reported that the marketable period of fresh-cut 'Tommy Atkins' and 'Kent' mango cubes was 3–5 d at $10\,°C$ and 5–8 d at $5\,°C$ and was limited by watery condition, discoloration, and loss of fresh appearance of the mango cubes. In another study, Gil et al. (2006) observed that fresh-cut 'Ataulfo' mango cubes maintained good visual quality up to 9 d of storage at $5\,°C$. However, the shelf-life of 'Nam Dokmai' mango cubes was 2 d at $5\,°C$ and 1 d at $13\,°C$, and was limited by browning and water soaking appearance on the cut surfaces (Poubol and Izumi, 2005a,b). As pointed out by Allong et al. (2001), the variability in shelf-life is mostly cultivar and maturity dependent, since mango fruit at different stages of ripeness may have different responses to fruit preparation (slicing), and may vary in physiological and metabolic activity. Furthermore, in this study, no significant difference in visual quality was noticed between slices from +HW- or −HW-treated fruit. This observation is in agreement with Plotto et al. (2006), who reported no significant difference between +HW and −HW fresh-cut 'Kent' mango slices after 0 and 6 d of storage at $7\,°C$, based on sensory descriptors (overall preference, firmness and mango flavor) evaluated by a panel of 16–18 members.

3.2. Respiration rate

Respiration rates were significantly affected by the storage duration for both harvests (Table 1). However, no common trend was observed between the harvests (Fig. 2). In H2, the CO_2 production of fresh-cut slices was higher than the corresponding whole fruit, which was not observed in H1. It is known that the increase in the respiration rate of fresh-cut compared with the intact product can range from only a few percent for green beans, grapes and zucchini to over 100% for kiwifruit and lettuce (Watada et al., 1996). The significant increase in respiration of fresh-cut slices at the end of the storage duration (day 8), for both harvests, may be due to an increase in microbial population on the cut surface since the spoilage on day 7 was noticeable by a trained person (Fig. 1). However, since no microbial testing was performed during this study no conclusion may be drawn.

The HW treatment had a significant effect on the respiration rates only in H2 (Table 2), where +HW fruit had higher respiration rates than −HW fruit. The difference was marked on day 0 and 4 (Fig. 2). Inconsistent respiration rate data for various fresh-cut mangoes was previously reported in the literature. It is difficult to determine if the respiration patterns in fresh-cut mangoes are due to cultivar variation, heat treatment, browning inhibition treatments (Beaulieu and Lea, 2003), or due to the cutting shape and ripeness stage at the time of cutting (Allong et al., 2001; Rivera-López et al., 2005). However, since in H2 the F-value for the type of fruit (fresh-cut vs. whole) was much higher than the F-value for the storage duration and the HW treatment, indicating a higher influence of the fruit sample on the respiration rate, and that no HW effect was present in H1, it is likely that the HW treatment does not have a specific effect on the respiration rates of fresh-cut 'Kent' mango slices stored at $5\,°C$ beyond the immediate effect while the whole fruit temperature is elevated during treatment.

3.3. Electrolyte leakage

Electrolyte leakage (EL) is an indicator of loss of cell membrane integrity attributed to ripening, and any damage that can arise from stress or mechanical injury (Nyanjage et al., 1999). The stage of fruit ripeness, duration of exposure to heat treatment, storage temperature, and their interactions may influence levels of EL (Nyanjage et al., 1999). Both leakage and respiration rate depend on fruit tissue integrity, and increase in these parameters should be expected at the end of ripening or when the fruit is exposed to severe stress

Table 1
ANOVA table for visual quality and aroma of fresh-cut 'Kent' mango slices.

Source of variation	d.f.	F-value				
		Overall color	Edge tissue damage	Aroma	Spoilage	Desiccation
Harvest 1						
Storage period	4	776.51***	85.89***	1164.11***	809.46***	556.94***
Hot water	1	<0.01 ns	2.97 ns	2.15 ns	3.92 ns	1.18 ns
Harvest 2						
Storage period	4	1059.67***	0.0001***	1693.76***	1874.54***	0.0001***
Hot water	1	0.48 ns	<0.01 ns	2.64 ns	1.10 ns	<0.01 ns

ns, *** = non-significant or significant at $P < 0.001$, respectively.

conditions (e.g. cutting/processing and/or exposed to high or low temperatures) (Vicente et al., 2006).

In this study, higher EL was measured on fresh-cut slices that were stored for a few days before analysis compared to the whole fruit that were cut at the moment of analysis (Table 2). High initial EL was most probably a reflection of the relatively advanced ripeness of the fruit at the time of processing. The overall levels of EL did decrease slightly through the 10-d storage duration for both harvests, although most of changes occurred after the slices had passed the marketable period. This decrease could be attributable to further ripening, as indicated by an increase in SSC (Fig. 5), that may have led to higher osmotic potential and thereby reduced electrolyte leakage (Nyanjage et al., 1999). In general, no HW effect was noticed for either harvest during the marketable period, although a significant difference was found on day 0 for H2 (Fig. 2), where the EL of −HW-treated fruit was higher than that of +HW-treated

fruit, however, the trend did not extend to the rest of the storage duration.

3.4. Firmness

Firmness decreased during storage with greater firmness losses occurring for the fresh-cut slices than for the whole fruit (Table 2, Fig. 3). In this study, all of the fresh-cut slices were processed a few hours later the initial whole fruit samples were cut, and then the firmness of all of the sample replicates was measured, which may have contributed to the initial lower firmness (day 0) of fresh-cut slices compared with whole fruit. There was no HW effect on firmness. This observation is contrary to what was found by Jacobi and Giles (1997) who reported that untreated fruit were firmer than vapor heat (VHT) or HW-treated mangoes, both 10 days after storage and at the eating ripe stage.
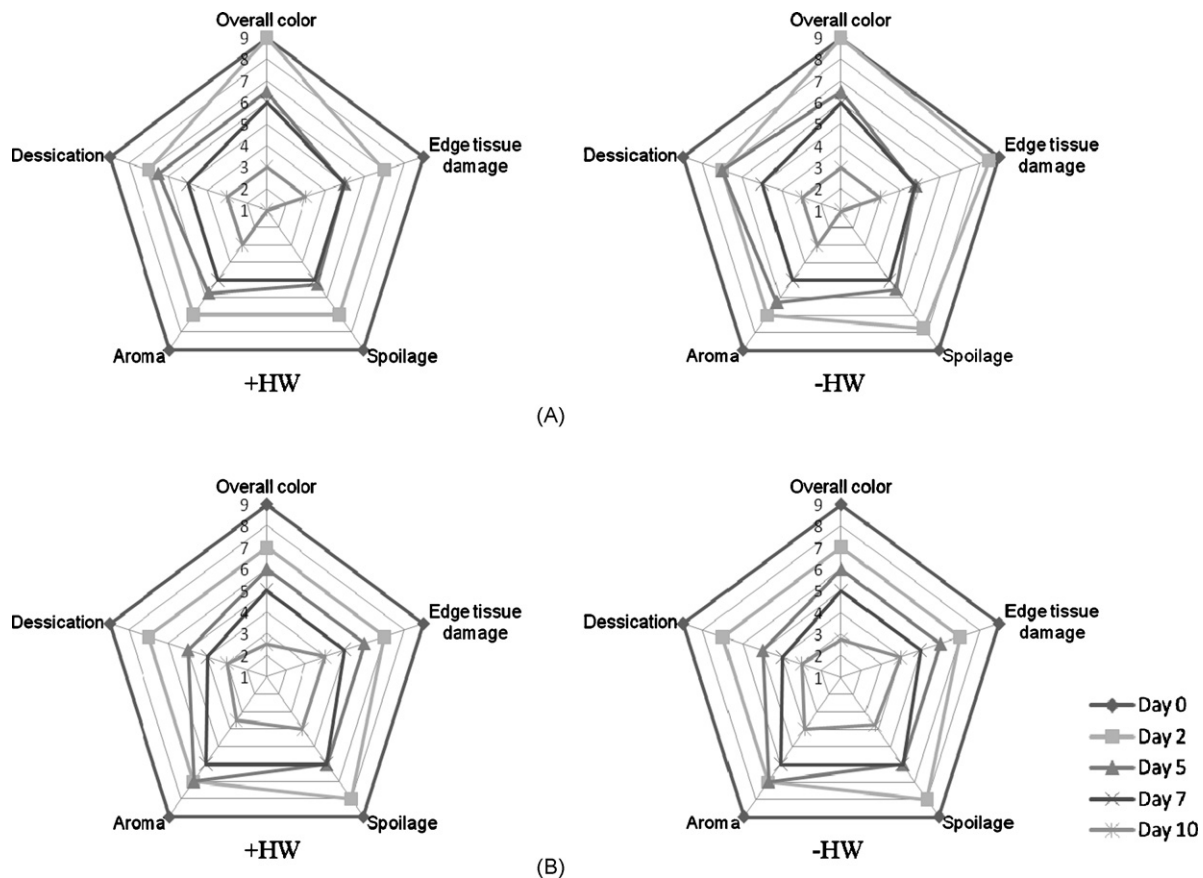

Fig. 1. Subjective visual evaluation of hot water-treated (+HW) and non-hot water-treated (−HW) fresh-cut 'Kent' mango slices during storage from (A) Harvest 1 or (B) Harvest 2. Generally: 9 = excellent; 7 = very good; 5 = limit, good; 3 = fair, absolute limit for household use with trimming and/or loss; 1, poor, inedible. Five is the minimum subjective score (limit) for marketing any product.
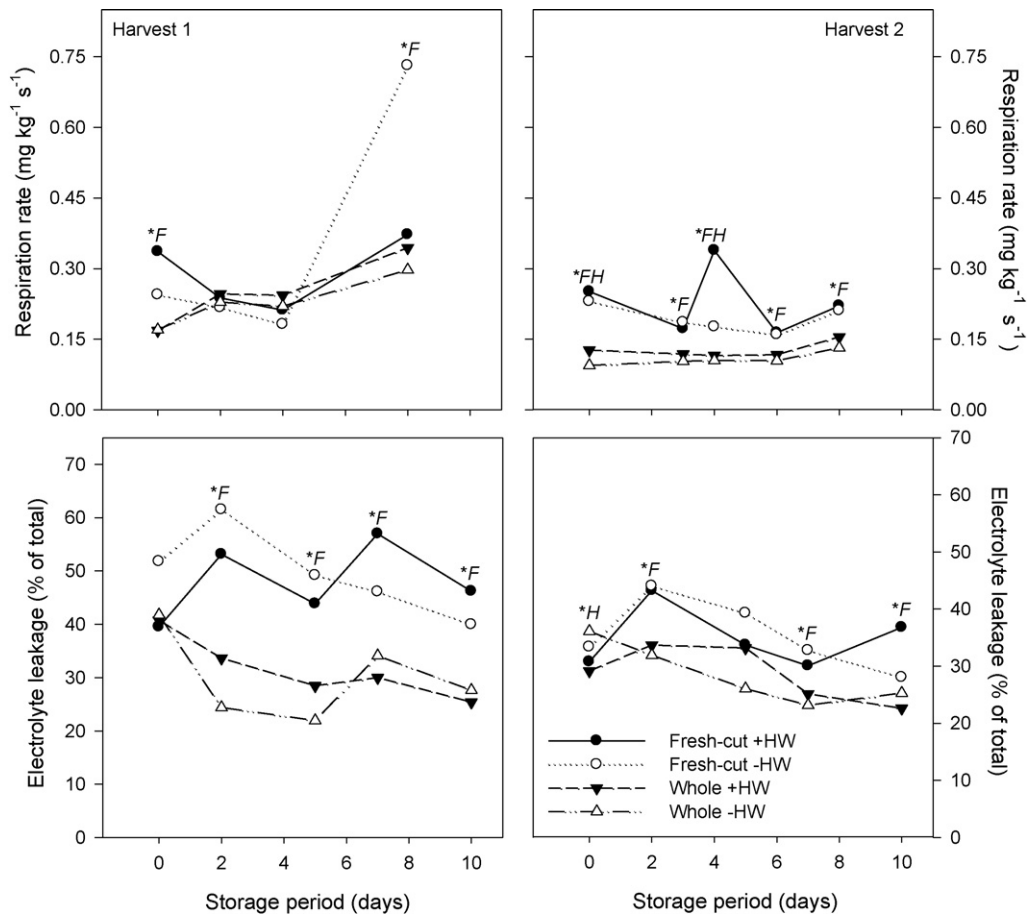
Fig. 2. Respiration rate and electrolyte leakage during storage of fresh-cut 'Kent' mango slices and whole mangoes from hot water (+HW) or non-hot water (−HW) treatments for Harvests 1 and 2. The symbols *F, *H or *FH for a specific storage day indicate significant differences at α = 0.05 between fresh-cut and whole fruit (*F), +HW and W (*H), or both (*FH), respectively, using LSD test.

3.5. Flesh color

For fresh-cut mangoes, a decrease in L^* value may be an indicator of flesh browning, and a decrease in hue angle indicates that flesh turns from yellow to orange-red. In this study, the flesh lightness (L^* value) decreased with storage time for the fresh-cut slices, indi-

cating a darkening of the surface color compared with the whole fruit, for which the flesh lightness tended to increase during storage (Fig. 3). This increase in lightness could be attributable to a loss of green color that occurred prior to a rise in yellow-orange as indicated by an increase in a^* value, which followed a similar pattern to the L^* value during storage (data not shown). Hue

Table 2
AVOVA table – respiration rates, electrolyte leakage, firmness, hue angle, lightness, and composition of fresh-cut 'Kent' mango slices and whole mangoes.

Source of variation	d.f.	F-values								
		RR[a] $(mg\,kg^{-1}\,s^{-1})$	EL[b] (% of total)	Firmness (N)	Hue angle (h°)	Lightness (L^*)	SSC (%)	AA $(mg\,kg^{-1})$	Total alcohols $(\mu L\,L^{-1})$	Total non-alcohol volatiles $(\mu L\,L^{-1})$
Harvest 1										
Storage period	4	13.07***	3.39*	–	–	–	3.03*	5.58***	3.08*	1.90 ns
Hot water (H)	1	0.31 ns	0.01 ns	–	–	–	13.24**	1.40 ns	0.68 ns	0.35 ns
Fresh-cut/whole fruit (F)	1	6.91*	79.66***	–	–	–	11.01**	2.09 ns	0.44 ns	0.12 ns
H × F	1	1.67 ns	0.86 ns	–	–	–	0.40 ns	3.86 ns	0.54 ns	0.59 ns
Harvest 2										
Storage period	4	5.53**	8.96***	72.02***	6.53***	5.48**	1.18 ns	8.32***	13.32***	2.11 ns
Hot water (H)	1	13.62**	0.04 ns	0.27 ns	4.72*	1.21 ns	9.96**	0.05 ns	0.00 ns	0.98 ns
Fresh-cut/whole fruit (F)	1	146.52***	27.75***	64.42***	0.33 ns	106.17***	102.62***	27.25***	20.79***	5.94*
H × F	1	1.69 ns	0.16 ns	1.67 ns	0.15 ns	0.12 ns	0.16 ns	3.65 ns	4.54**	1.78 ns

ns = non-significant.
 [a] Respiration rate.
 [b] Electrolyte leakage.
 * Significant at $P < 0.05$.
 ** Significant at $P < 0.01$.
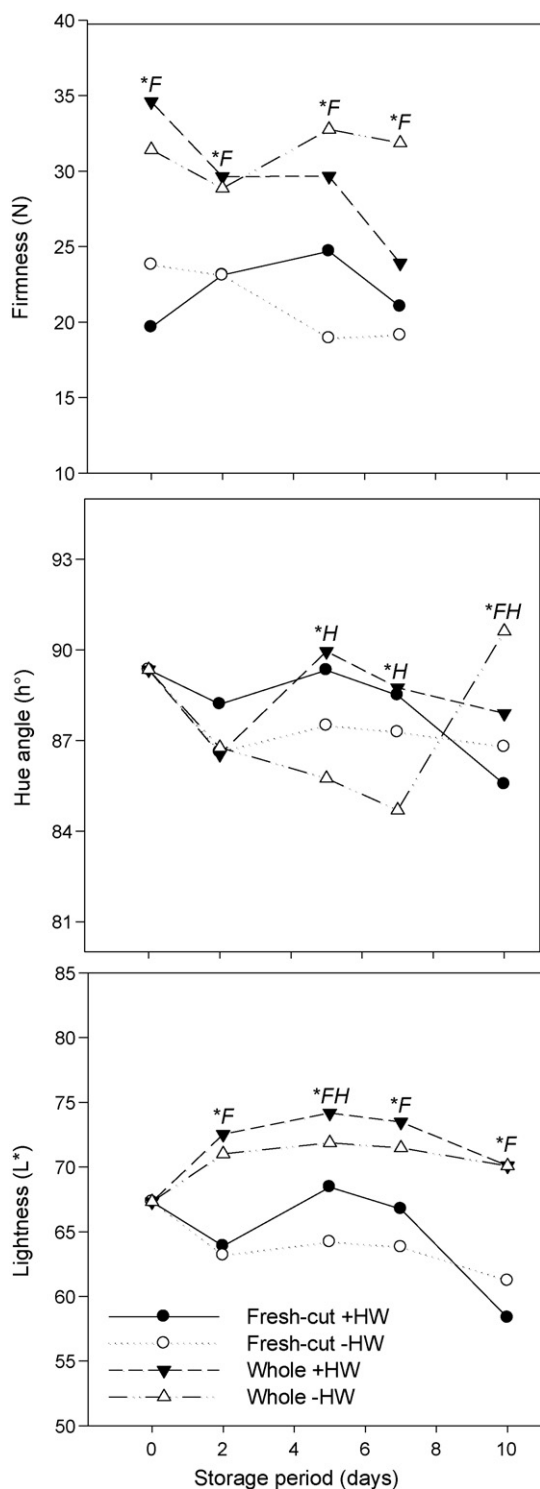 *** Significant at $P < 0.001$.

Fig. 3. Changes in firmness, hue angle, and lightness during storage of fresh-cut 'Kent' mango slices and whole mangoes from hot water (+HW) or non-hot water (−HW) treatments for Harvest 2. The symbols *F, *H or *FH for a specific storage day indicate significant differences at $\alpha = 0.05$ between fresh-cut and whole fruit (*F), +HW and −HW (*H), or both (*FH), respectively, using LSD test.

angle did not follow any specific trend (increase or decrease) even though a significant difference during storage was found, possibly due to slice color variations within sample replicates related to initial fruit-to-fruit variability. In this study, no difference in L^* value among the HW treatments was noticed, but +HW-treated fruit had higher hue angle values than −HW-treated fruit. This was

the opposite of results reported by Jacobi and Giles (1997) for 'Kensington' mangoes, where heat treatment caused a higher lightness and a lower hue angle to develop during ripening. While, Kim et al. (2007) reported no differences in color values between HW-treated and control fresh-cut 'Tommy Atkins' mango slices.

3.6. Fruit composition

3.6.1. pH, titratable acidity, soluble solids content

The pH increased significantly throughout storage for all treatments and both harvests (Table 2; Fig. 4). Although there was a statistically significant effect of storage time on pH, the pH changes were so small (≤ 0.2 units) that it would be practically impossible to detect such differences between fruit by taste evaluations. Therefore, pH changes through time for either fresh-cut slices or whole fruit were not considered different. It has been previously reported that there were no significant changes in pH during the storage of fresh-cut mangoes (Paull and Chen, 2000; Gil et al., 2006; González-Aguilar et al., 2007). In addition, it has been reported for fresh-cut cantaloupe, that a biochemical parameter such as pH cannot be used as an indicator of quality because it does not change significantly from amounts present in the freshly cut fruit when stored at 4 °C for a period of 2 weeks (Lamikanra and Richard, 2002). No significant trend for pH was found in the fruit in terms of HW treatment or whole versus fresh-cut (Table 2). Gil et al. (2006) reported no significant changes in titratable acidity (TA) during storage of fresh-cut 'Ataulfo' mango cubes at 5 °C. Moreover, it was shown that TA of whole mangoes (c.v. Haden and Kent) decreased with ripening at 24 °C, but increased at 13 °C, and changed only slightly at 5 °C (Tovar et al., 2001). In the present study, however, the acidity of fresh-cut and whole mango decreased slightly during storage for both H1 and H2 (Fig. 4). The overall TA was significantly affected by the HW treatment in H1, where −HW had a higher TA value that the +HW-treated fruit. This difference was significant at day 0 and 7 (Fig. 4). These findings are in accordance to those reported by Paull and Chen (2000), where TA was reduced in heat-treated nectarines and strawberries. The significant interaction between HW and fresh-cut processing reflects treatment differences that occurred after the marketability was compromised. However, since no difference due to HW treatment was observed in H2, no conclusion can be drawn as to whether the HW treatment had a significant impact on TA of fresh-cut slices or whole mango. The SSC increased slightly (Table 2, Fig. 5) during storage in H1, indicating that the fruit may have continued to ripen during storage with residual starch converted into sugars. No SSC change was observed in H2. Similarly, SSC in 'Julie' and 'Graham' mango fresh-cut slices held at 5 or 10 °C increased during storage (Allong et al., 2001), while no significant changes in SSC were measured during the storage of several other cultivars of fresh-cut mangoes held at 4 or 5 °C for periods of 8–14 d (Rattanapanone et al., 2001; Gil et al., 2006; González-Aguilar et al., 2007). For both harvests, whole fruit had significantly higher SSC than the fresh-cut slices with no regard to if fruit were HW-treated or not, which was similar to the results of Tovar et al. (2000), who reported that partially ripe 'Kent' mango slices continued to ripen after cutting, but did not reach the same level of ripeness as whole mangoes did after 5–7 d at 13 or 23 °C. For H1, the −HW-treated fresh-cut slices and whole fruit had higher SSC than the +HW treatments, but significant differences were evident past the marketable period (Fig. 5). For H2, −HW-treated fruit had significantly higher SSC only on day 0 and day 7. Rattanapanone et al. (2001) reported that SSC did not change significantly as a function of temperature, atmosphere or storage time in fresh-cuts prepared from ripe, heat-treated mangoes ('Kent' and 'Tommy Atkins') held at 5 or 10 °C. Moreover, Paull and Chen (2000) reported no significant effects of heat treatment on SSC for mango, grapefruit, orange and tomato.
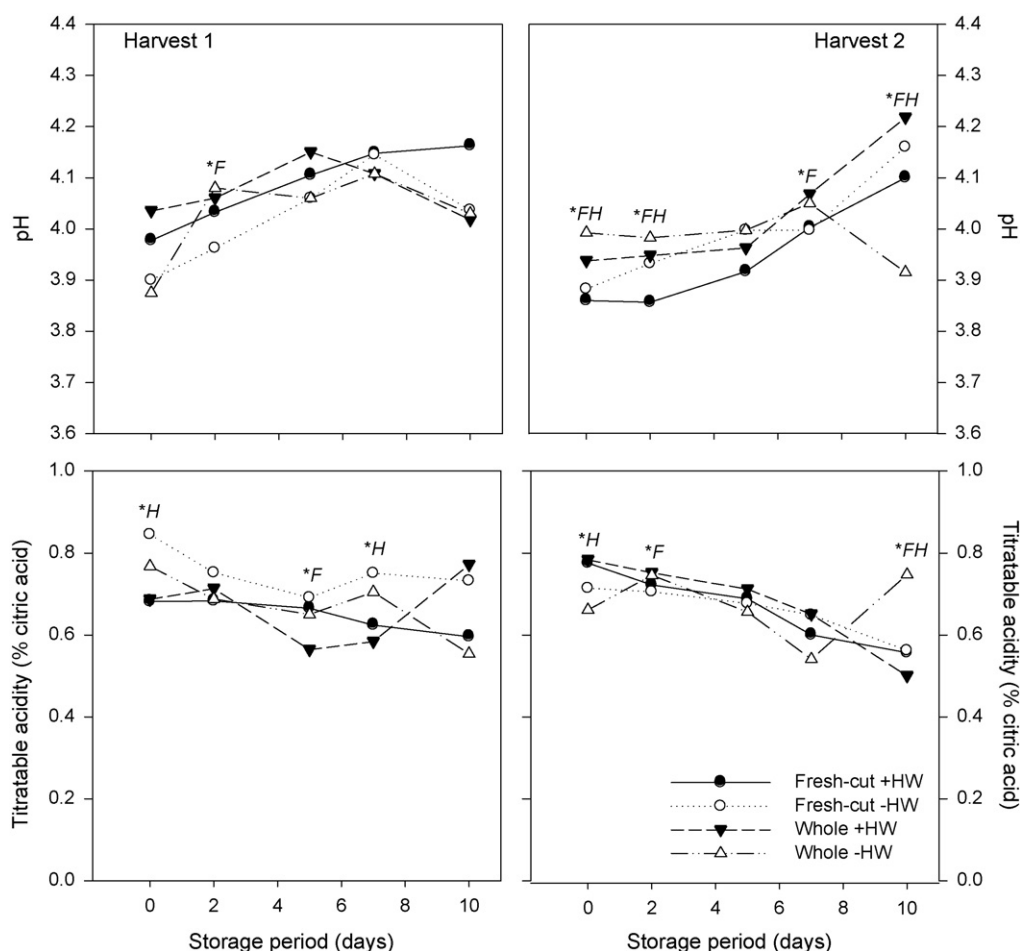
Fig. 4. Changes in pH and titratable acidity during storage of fresh-cut 'Kent' mango slices and whole mangoes from hot water (+HW) or non-hot water (−HW) treatments for Harvests 1 and 2. The symbols *F, *H or *FH for a specific storage day indicate significant differences at $\alpha = 0.05$ between fresh-cut and whole fruit (*F), +HW and −HW (*H), or both (*FH), respectively, using LSD test.

3.6.2. Total ascorbic acid

The initial amounts of total ascorbic acid (AA) expressed on a fresh weight basis were different in the two harvests (Fig. 5); the AA levels for H1 were much higher than for H2, which could be explained by different climatic conditions and/or the location where the fruit were harvested (Lee and Kader, 2000). For both harvests, the concentration of AA changed during storage (Table 2). Actually, for H1, AA was significantly lower past the marketable period. While for H2, AA was initially lower on day 0. It has been reported that AA degrades very little during short-term refrigerated storage (about 1 week) in some fresh-cut fruits (Beaulieu and Gorny, 2004). Tovar et al. (2001) reported that the AA concentration in mango decreased as ripening progressed while the opposite occurred in fresh-cut slices. In fact, the AA content of the slices kept at 5 or 13 °C increased during storage but never reached the level of the whole fruit. Other authors (Thomas, 1975, Thomas and Joshi, 1988) have reported increases in AA during refrigerated storage (5, 7, 10 or 15 °C) of 'Alphonso' mangoes and suggested ascorbate synthesis under such conditions. Ôba et al. (1994) demonstrated that activity of L-galacto-γ-lactone dehydrogenase was induced and was responsible for ascorbate synthesis in injured tissue of potato tubers; which suggests that the same may occur in injured mango tissue. The hypothesis that the increase of AA concentration on a fresh weight basis during storage may be due to water loss during storage rather than to actual increase in AA (Nunes et al., 1998) is not supported in this case since the percentage of weight loss (data not shown) was less than 0.5% of the initial weight and

no exudates were noticed in the containers of fresh-cut fruit. No difference between AA content of whole and fresh-cut slices was observed for H1, while for H2, AA content of fresh-cut slices was lower than in the whole fruit. It is known that levels of AA can decrease after processing or during ripening. Since oxidative processes occur more rapidly in fresh-cut products, they are expected to have more AA losses compared with the whole fruit (Allong et al., 2000) mostly due to the loss of compartmentalization of the cells, allowing degradative enzymes and substrates to come into contact. Moreover, no difference in AA content between HW treatments was found in this study.

3.6.3. Volatiles

For ease of comparison, the 16 volatiles measured were grouped and compared. Therefore, all of the aldehydes (acetaldehyde, hexanal), one ketone (acetone), the terpenes (α-pinene, β-pinene, limonene, ρ-cymene, α-copaene, 3-carene, myrcene, terpinolene and caryophyllene) and the esters (ethyl acetate and ethyl butyrate) were summed and presented as total volatiles; ethanol and methanol were summed separately and presented as total alcohols (Fig. 6). No significant differences were observed among all sources of variation for total volatiles content in samples from H1. In fact, when analyzing each individual volatile compound separately, only β-pinene, limonene, and ethyl butyrate presented significant higher concentrations on day 7 (and day 2 for limonene). No differences were found between whole fruit and fresh-cut slices during storage. Total alcohol content also varied during stor-
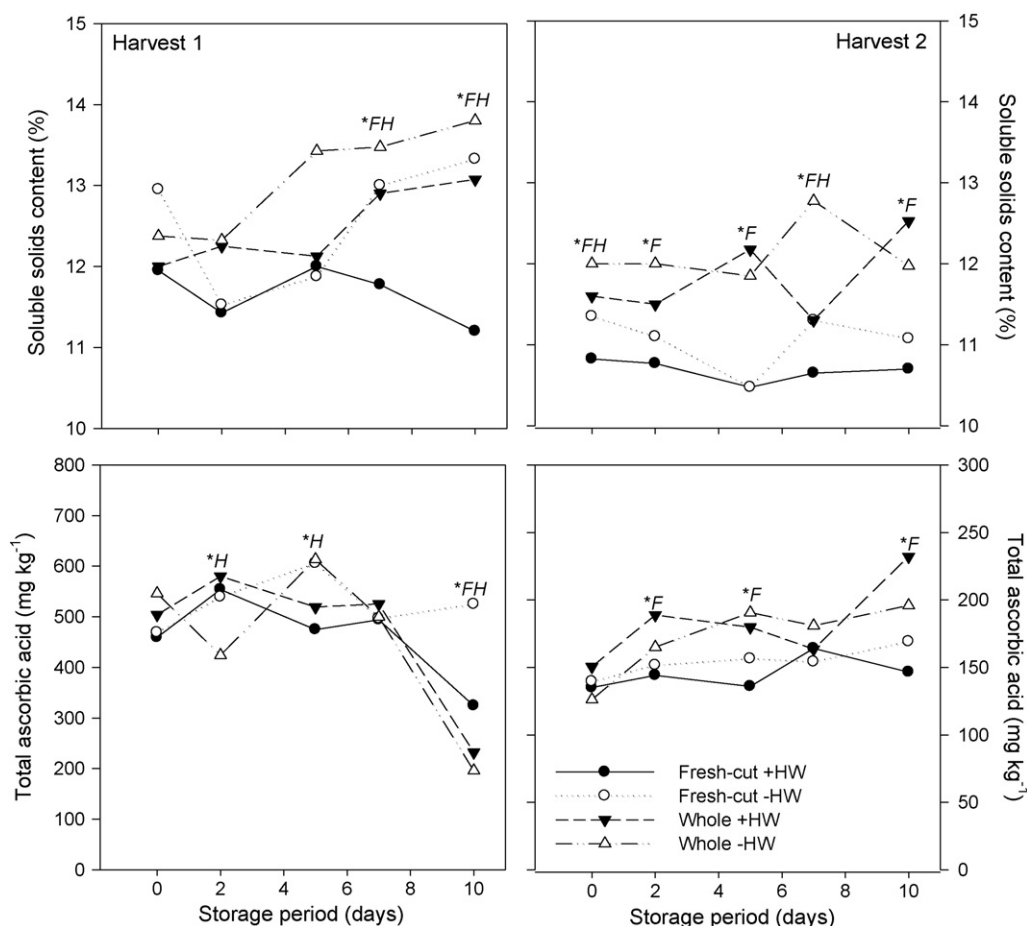
Fig. 5. Changes in soluble solids content and total ascorbic acid during storage of fresh-cut 'Kent' mango slices and whole mangoes from hot water (+HW) or non-hot water (−HW) treatments for Harvests 1 and 2. The symbols *F, *H or *FH for a specific storage day indicate significant differences at $\alpha = 0.05$ between fresh-cut and whole fruit (*F), +HW and −HW (*H), or both (*FH), respectively, using LSD test.

age (Table 2), with the least alcohol content present at day 10 (Fig. 6). For H2, however, there was much higher content of alcohols (mainly ethanol) on day 10 of storage and the levels were significantly higher for the fresh-cut slices than the whole fruit. Moreover, fresh-cut slices had higher total volatile content than whole fruit in H2. This effect was marked on the last day of storage. Acetaldehyde, acetone, α-pinene, limonene, ρ-cymene, α-copaene and terpinolene were the only volatiles to present a significant difference in H2 during storage (data not shown). In fact, higher concentrations were present in the whole fruit compared with the fresh-cut slices, except for acetaldehyde, which was present in higher concentrations in fresh-cut slices compared with whole fruit. Beaulieu and Lea (2003) suggested that volatile production by fresh-cut mangoes could undergo a transient upsurge because skin removal creates secondary compound formation (i.e. terpenes and aldehydes), allows rapid off-gassing, and increases available O_2 for enzymatic action. Through storage, as starch declines and less sugar is catabolized, less acetyl-CoA would be available as substrate for continued volatile production. In this experiment, a slight decline in total volatiles was observed during storage at 5 °C. During storage of fresh-cut chunks processed from commercially mature melons, the total volatile concentration generally increased during the first 2 d of storage and then remained relatively stable or decreased gradually during the reminder of storage (Saftner et al., 2006). No significant difference between fresh-cut slices and whole fruit were noticed in H1, but for H2, fresh-cut slices had significantly higher total volatiles, mainly due high acetaldehyde concentration, compared to whole fruit at the end of the storage at 5 °C.

The high content of acetaldehyde and ethanol present in the slices may be attributable to fermentative processes that occurred during storage. It is known that anaerobic respiration in fruit tissue is characterized by increases in ethanol, ethyl acetate, ethyl butanoate, and acetaldehyde during storage (Beaulieu and Lea, 2003). The major plant fermentative metabolism products in fruits are ethanol and acetaldehyde and their accumulation is well-correlated with off-flavor development (Agar et al., 1999). For example, Sothornvit and Rodsamran (2008) reported that both storage time and temperature significantly affected 'Nam Dokmai' mango flavor, and panelists indicated that off-flavors caused by the release of alcohol and acetaldehyde were the main attributes negatively affecting mango flavor. However, acetaldehyde and ethanol appear to be normal components of ripe mango since both are present in mango fruit at the beginning of ripening and before storage, and their levels normally increase during ripening, even in air (Bender et al., 2000). Objectionable concentrations of ethanol and acetaldehyde due to fermentative metabolism may appear before the visual quality declines and limits the shelf-life of fresh-cut fruits. For example, fresh-cut orange segments that had acceptable appearance after 14 d of storage at 4 °C were found to have unacceptable flavor quality after only 5 d (Beaulieu and Gorny, 2004). Likewise, undesirable flavor was the limiting factor in sliced and wrapped watermelon stored for 7 d at 5 °C, even though the aroma was still acceptable and microbial populations were not problematic after 8 d (Saftner et al., 2006). In this study, the HW treatment did not affect the levels of total volatiles and alcohols in mango tissue for either of the harvests. Similar results were found by Plotto et al. (2006), who found
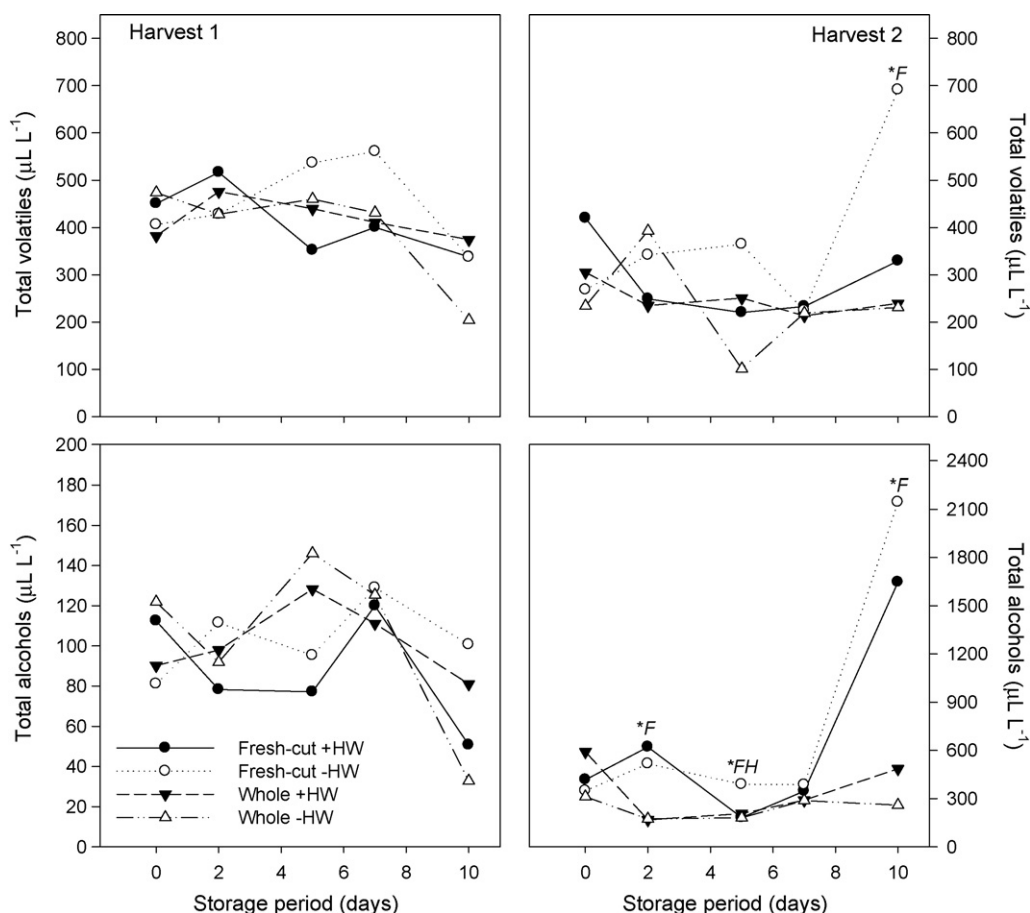
Fig. 6. Changes in total volatiles (aldehydes, ketones, terpenes and esters) and total alcohols (methanol and ethanol) during storage of fresh-cut 'Kent' mango slices and whole mangoes from hot water (+HW) or non-hot water (−HW) treatments for Harvests 1 and 2. The symbols *F, *H or *FH for a specific storage day indicate significant differences at $\alpha = 0.05$ between fresh-cut and whole fruit (*F), +HW and −HW (*H), or both (*FH), respectively, using LSD test.

that the levels of acetaldehyde, ethanol, and β-pinene did not differ between +HW and −HW-treated 'Kent' mango pieces stored for 2 weeks at 7 °C in clamshells. Moreover, it has been reported by several authors (Paull and Chen, 2000; Jacobi et al., 2001; Dang et al., 2008) that whole mangoes that are undamaged by heat treatment (either hot water or hot air) have organoleptic qualities (i.e., flavor, aroma, pH, TSS, and TA) that are comparable to those of untreated fruit.

4. Conclusion

Edge or tissue damage and desiccation of the slices were the most obvious visual quality changes observed in ripe, fresh-cut 'Kent' mango slices, limiting the shelf-life to 5 d at 5 °C. No HW treatment effect was found in this experiment for the visual quality, respiration rate, firmness, pH, TA, AA, total volatiles, or alcohols, but fresh-cut slices from non-HW-treated fruit had higher SSC than the HW-treated samples. Overall, the results suggest that the HW quarantine treatment used in this study and required by the USDA to be applied to mangoes entering the USA does not have a significant effect on the quality of fresh-cut 'Kent' mango slices prepared from those fruit and stored at 5 °C. In this study, HW treatment was performed under optimal conditions, using fruit that were at a more advanced ripeness stage than typical commercially harvested mangoes, and the HW treatment was followed by appropriate cooling, which is not always done commercially and may have improved the recovery rate of treated fruit. Thus, the fact that the HW treatment in this study did not cause injury to the mangoes and did not affect the quality of the fresh-cut fruit during subsequent storage at 5 °C

may not be representative of the commercial situation. In fact, it is common to observe symptoms of heat injury on mangoes available on the market, due to improper quarantine heat treatment; therefore, it would be interesting to repeat this study under non-optimal conditions in order to observe the effect of treating unripe mangoes with HW on fresh-cut quality following storage.

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